

SEAFLOOR GEOMORPHOLOGY, GAS AND FLUID FLOW, AND SLOPE FAILURE ON THE SOUTHERN CASCADIA CONTINENTAL MARGIN

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LONG TERM GOAL

The long term goal of this project is to understand how tectonics, gas, and hydrogeology act as forcing agents in the creation and modification of submarine geomorphology.

SCIENTIFIC OBJECTIVES

The objective of this project is to evaluate the role of fluid flow, overpressuring, and gas migration in the creation of failure features on the seafloor of a tectonically active continental margin. This project addresses questions about: 1) the lateral and vertical extent of detectable overpressured fluids and gas in the subsurface, 2) gas-related structures and manifestations of flow on the surface, 3) seafloor geomorphology related to gas and fluid expulsion, and 4) structural controls on gas and fluid conduits and expulsion sites.

We pursue answers to these questions using a combination of theoretical and observational analyses. Observations and hypotheses based upon remote sensing data collected in previous years (seismic reflection surveys with frequencies ranging from ~15 Hz to ~3.5 kHz, sidescan sonar surveys, high resolution bathymetry) were recently groundtruthed with direct seafloor observation and sampling using a remotely operated vehicle (ROV) in August, 1997. Our continuing work on remote sensing data and our recent ROV observations will become the basis for modeling the relationship between gas-charged fluids and slope failure. Fulfillment of these objectives will allow us to obtain a better understanding of the dynamic processes occurring on the southern Cascadia continental shelf and slope, and ultimately help address how sediment is transported from the shelf to upper slope, and from the upper slope to abyssal depths.

APPROACH

The Eel River basin experiences remarkably high sedimentation and tectonic uplift rates, and is known to be gas-prone in the subsurface. Based on our hypothesis that gas and overpressured fluids have an effect on slope stability in Southern Cascadia, we have continued our work cataloging and correlating subsurface gas and fluid distribution with geomorphic features on the seafloor. We first use industry-quality multichannel seismic reflection data to determine the regional structural trends within the Eel River basin and document the general distribution of gas, gas-related features (e.g. mud volcanoes, breached anticlines, or diapirs), and overpressured fluids. We then compare the distribution of gas and overpressured fluids with large-scale failure features noted on high-resolution bathymetric and acoustic reflectivity data. Use of high-resolution sidescan sonar and high resolution seismic reflection data facilitate documentation of localized areas of fluid seepage sites and finer-scale surface failure features. We have also utilized industry "sniffer" data to look for evidence of gas in the water column to constrain areas that are presently venting gas and fluids. Observations and interpretations based upon these data were used to locate ROV dive targets and transects, and provide us with a framework for geologic modeling.

ACCOMPLISHMENTS AND RESULTS

Pockmarks

The distribution of pockmarks in the Eel River basin offshore northern California provides insight into gas+fluid migration and sedimentation processes acting on the shelf and slope of the continental margin.

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Pockmarks, conical depressions on the seafloor, serve as proxies for locations of discrete gas+fluid venting from depth. Numerous pockmarks that litter the seafloor of the Eel River basin indicate active gas+fluid expulsion is occurring or has recently occurred in this gas-rich sedimentary basin. The distribution and number of pockmarks on the seafloor appears to be inversely related to the location and amount of natural gas observed in the subsurface and inversely related to the locations of gas plumes in the water column. The large number of pockmarks observed (up to 80 pockmarks per 500 meters along track) and size of each pock (>10m diameter) indicate that gas+fluid expulsion through pockmarks may be a significant force in redistributing sediment. The absence of pockmarks on the shelf contrasts with a large number of pockmarks observed on the slope, indicating spatially different sedimentation rates and varied modes of gas+fluid transport in this basin.

Correlation of surface failure features such as pockmarks with subsurface natural gas suggests hydrocarbon migration may be a significant geomorphic forcing mechanism acting on the seafloor of the continental margin. Analysis of seismic data in the Eel River basin shows that although natural gas in this area is abundant, it is regionally variable and controlled more by stratigraphy than by structure. The abundant gas detected in this basin likely plays a role in changing sediment strength and slope stability, and affects both seafloor morphology and sediment transport from the shelf to the slope to abyssal depths.

Preliminary ROV Observations

Observations made during an 11-day ROV program in August, 1997 indicate that gas and fluids are being actively expelled only along structural features in the Eel Basin, suggesting that the geomorphic features observed on the slope were created some time in the past under different conditions. In contrast, on the shelf high rates of sedimentation and/or the increase in sand are effectively obliterating surface evidence of past fluid expulsion events.

Abundant pockmarks catalogued using 1995 and 1996 SIS-1000 Huntex side scan sonar data and the 1995 EM-1000 high resolution bathymetry show an increase of expulsion-related features on the upper slope of the continental margin, with the highest concentration of pockmarks near the Humboldt Slide. Such features were observed on high-resolution seismic reflection data as well. ROV dives into these pockmarks, however, indicate that these features are presently inactive and act as sediment sinks. Because sediment has infilled these craters, it was impossible to visually tell where pockmarks were located. We relied heavily on the ROV's sonar and bathymetry system to locate these large, broad features. No pockmarks smaller than ~10m diameter were encountered. This is the same approximate size as the pockmarks observed using the SIS-1000 sidescan sonar. We estimate that within the STRATAFORM area, over $6.6 \times 10^5 \text{ m}^3$ of sediment has been redistributed by fluid expulsion out of pockmarks. This same volume of space is presently acting as a sink. Using a rough estimated sedimentation rate of 3cm/yr, the pockmarks formed less than 100 years ago and have since been a sedimentary sink.

On the shelf, ROV observations also indicate that gas and fluid venting do not change the local seafloor morphology. Previous analyses of 3.5 kHz data suggested widespread active venting on the shelf, and analyses of industry seismic reflection data showed abundant subsurface gas that parallels isobaths. ROV observations, however, suggest most vents are fault-controlled, although dive locations were limited due to time constraints. The ROV observations correlate well with data from side scan sonar, which showed virtually no pockmarks on the shelf. It is likely that the sandy and wave-washed nature of the shallow (50m and less) shelf prevents the preservation of expulsion-induced geomorphic features. Vent sites consist of broad areas of seafloor covered by bacterial mats, as well as small (<2 cm diameter) holes on the seafloor actively venting intermittent streams of gas bubbles. Two cores suggest microfaults are acting as permeable conduits for flow. Active vents studied using the ROV were all located along fault zones.

Based on these observations and data from multichannel seismic reflection data, we suggest that much of the geomorphology between structures was created during episodic, catastrophic events. This hypothesis is supported by data observed the high resolution multichannel seismic reflection data (collected in 1996 by Fulthorpe and Mountain) and observations made using an industry-quality data set. These data collectively show that the Humboldt Slide has failed repeatedly in the past, and that gas and fluids are presently trapped in the body of the slide along slide planes.

Extension of Slope Morphology Studies to Other Margins

Our previous study into headless canyon formation (initiated as part of ONR N00014-93-1-0202) lead us to the question of slope stability on seismically active margins (e.g.: the Humboldt Slide). How is it that the steepest local slopes occur in a region that produces some of the largest earthquakes in the world? Is it possible that a 18° slope is somehow more stable in Cascadia than a 1° slope in the Gulf of Mexico, almost 1,000 km from the nearest seismic center? Using NOAA bathymetry with 100 m grid spacing and GLORIA

side-scan sonar data, we have mapped almost 100 discrete landslides on the continental slopes of Oregon, California, Gulf of Mexico (GOM), and New Jersey/ Maryland. Each margin represents a different tectonic environment- the convergent Oregon with the possibility of a 'megathrust' earthquake every 600 or so years, the transform California margin with a narrow shelf, highly eroded slopes and frequent earthquakes, the salt tectonics province of the GOM, and the passive New Jersey/ Maryland slope with canyons similar to California, but far from the Charleston and Nova Scotia seismic centers. The study shows that Oregon has the fewest and smallest slides and the GOM has the most and the largest by more than an order of magnitude. The California and New Jersey/Maryland slopes have very similar size and distribution of landslides, suggesting that similar processes may be at work

SCIENTIFIC IMPACT, TRANSITIONS AND ACCOMPLISHMENTS

Our studies show abundant subsurface gas and evidence of gas+fluid expulsion in areas containing surface failure features in Southern Cascadia, which strongly suggests a causative link between gas and changes in seafloor geomorphology. Given that natural gas is a common occurrence on continental shelves worldwide, results from this project should be suitable for extrapolation to other area, especially in sedimentary basins that experience high sedimentation rates and/or are near tectonically active margins. We are also beginning to examine slope morphology in general in a number of tectonic settings to determine the forcing functions acting in each of these settings.